FLEXURAL STRENGTHENING OF RC

Beams - slabs

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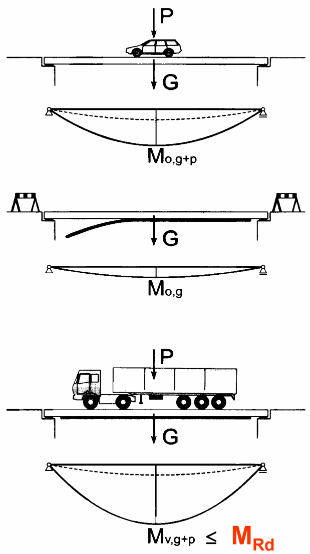
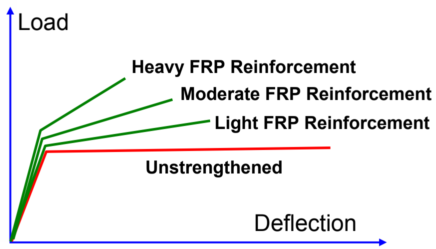
FLEXURAL STRENGTHENING





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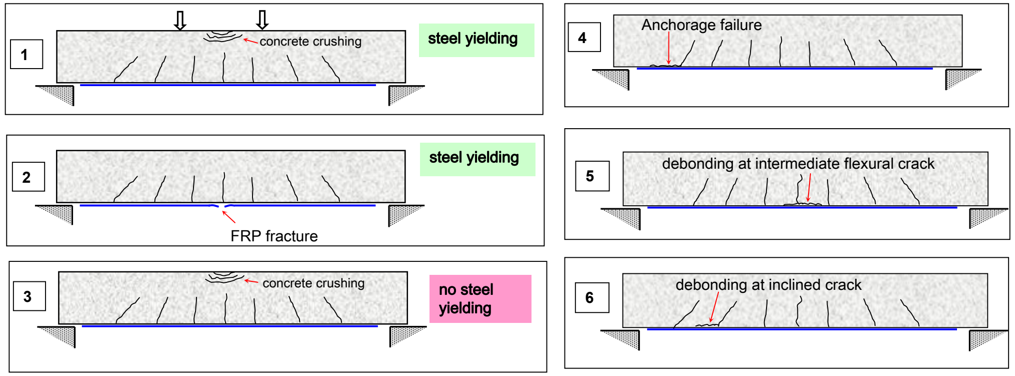
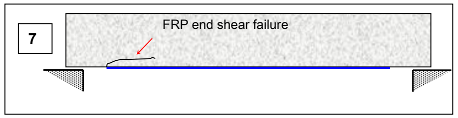
FAILURE MECHANISMS

FULL COMPOSITE ACTION

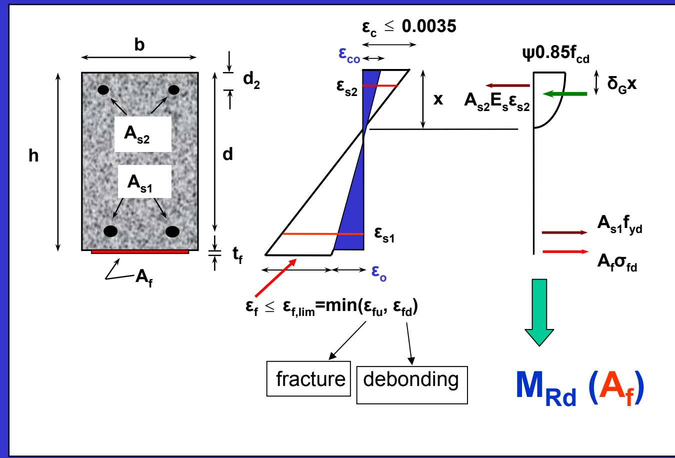
DEBONDING





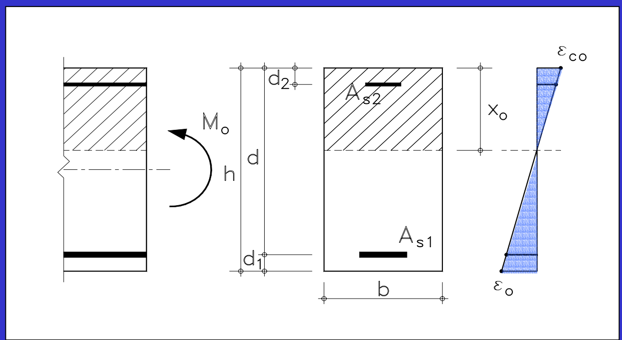
SHEAR FAILURE
AT FRP END

CROSS SECTION ANALYSIS AT THE ULTIMATE LIMIT STATE



Initial Situation

(During Strengthening)



$$M_{Rd} = \frac{1}{\gamma_{Rd}}\left[A_{s1}f_{yd}\left(d-\delta_G\cdot x\right)+A_f\sigma_{fd}\left(h-\delta_G\cdot x\right)+A_2 f_{sd2}\left(\delta_G\cdot x-d_2\right)\right] \quad (1)$$

$$\psi\cdot 0.85 f_{cd}bx + A_{s2}f_{sd2} = A_{s1}f_{yd} + A_f\sigma_{fd} \quad (2)$$

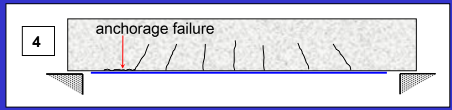
$$f_{sd2} = \varepsilon_c\frac{x-d_2}{x}E_s \le f_{yd} \qquad \varepsilon_f = \varepsilon_c\frac{h-x}{x}-\varepsilon_o \le \varepsilon_{f,lim} \quad (3)$$

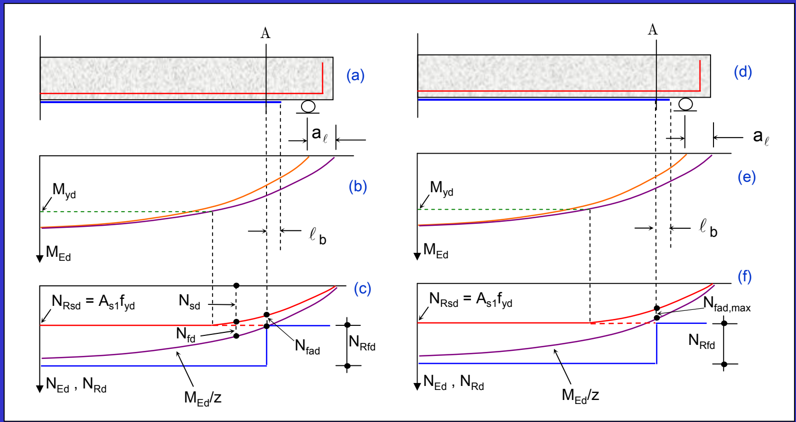
$$\psi = \begin{cases} 1000\varepsilon_c\left(0.5-\frac{1000}{12}\varepsilon_c\right) & \text{if } \varepsilon_c \le 0.002 \\ 1-\frac{2}{3000\varepsilon_c} & \text{if } 0.002 \le \varepsilon_c \le 0.0035 \end{cases}$$

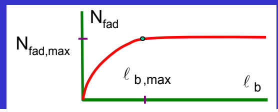
$$\delta_G = \begin{cases} \frac{8-1000\varepsilon_c}{4\left(6-1000\varepsilon_c\right)} & \text{if } \varepsilon_c \le 0.002 \\ \frac{1000\varepsilon_c\left(3000\varepsilon_c-4\right)+2}{2000\varepsilon_c\left(3000\varepsilon_c-2\right)} & \text{if } 0.002 \le \varepsilon_c \le 0.0035 \end{cases}$$

To prevent debonding at end crack

→ Compute required anchorage length

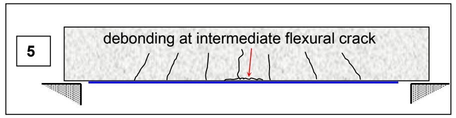






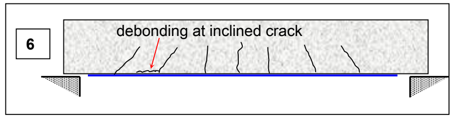
$$\varepsilon_{fd,fl} \approx \frac{\alpha_{fl}}{\gamma_{fd}}\sqrt{\frac{0.6k_b f_{ctm}}{E_f t_f}}$$

2.5 → α_{fl}



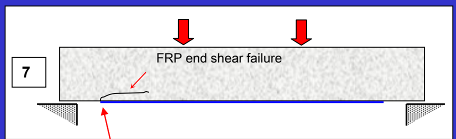
$$\varepsilon_{fd,fl-sh} \approx \frac{\alpha_{fl-sh}}{\gamma_{fd}}\sqrt{\frac{0.6k_b f_{ctm}}{E_f t_f}}$$

2.0 → α_{fl-sh}



Simplified method: $\varepsilon_{fd} \approx 0.5 - 0.8\%$

FRP end shear failure (concrete rip-off)

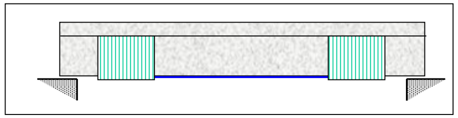


$$V_{Ed,end} \leq 1.4 V_{Rd,c}$$

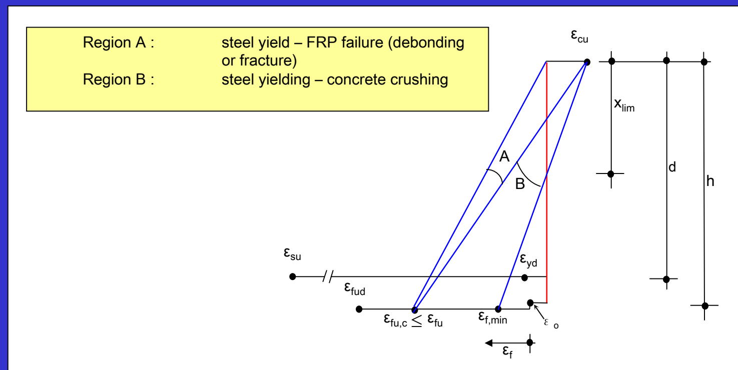
$$M_{Ed,end} \leq \frac{2}{3} M_{Rd}$$

If not verified :

SHEAR STRENGTHENING



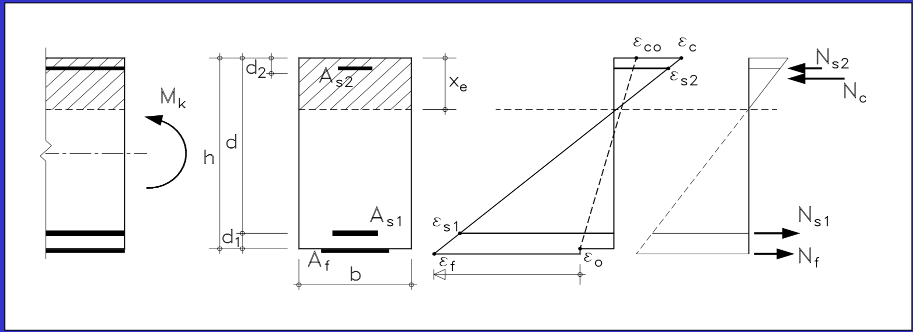
Ductility Requirements



Minimum required FRP strain for given curvature ductility μ_ϕ

$$\varepsilon_{f,min} = \varepsilon_{yd}\frac{\mu_\phi}{\left(\frac{d}{h}-\frac{x_y}{h}\right)}\frac{h}{d} - \varepsilon_{cu} - \varepsilon_o$$

Serviceability Limit State

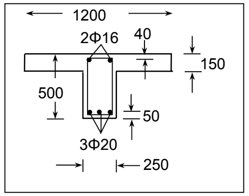


Check on FRP strain :

$$\sigma_f = E_f\left(\varepsilon_c \frac{h - x_e}{x_e} - \varepsilon_o\right) \leq \eta f_{fk}$$

$\eta = 0.8$ (carbon)
0.5 (aramid)
0.3 (glass)

EXAMPLE



Simply supported T-beam

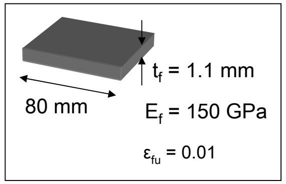
Span = 5 m f_{cd}=13.5 MPa f_{ctm}=2.2 MPa f_{yd}=435 MPa

g_d = 15 kN/m q_d = ~~30 kN/m~~ → **50 kN/m**

$V_{Rd,c}$= 40 kN

M_o = 15x5²/8 = 46.9 kNm ε_o = 0.00064

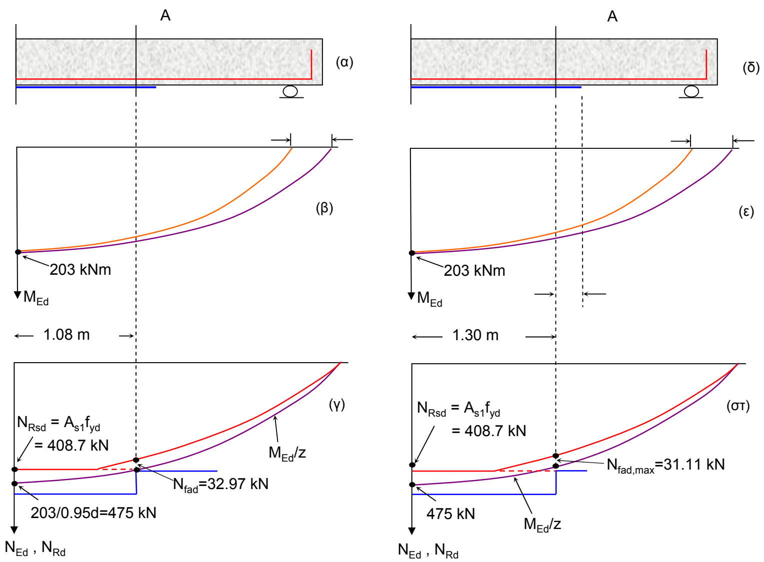
M_{Ed} = (15+50)x5²/8 = 203 kNm



Debonding strain: ε_{fd} = 0.0047
$\varepsilon_{f,lim}$ = min(0.0047, 0.01) = 0.0047

Section analysis → x=78 mm, ε_c = 0.00099, A_f = 93 mm²
2 strips → A_f = 93 mm² → M_{Rd} = 209 kNm

Calculations for anchorage failure



FRP end shear failure

$$M_{Ed,end} = 65 \times 1.00 \times \left(\frac{5}{2} - \frac{1.00}{2}\right) = 130\text{ kNm} < \frac{2}{3} M_{Rd} \quad \text{OK}$$

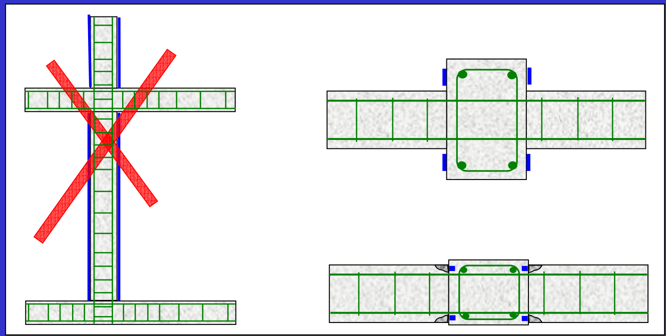
$$V_{Ed,end} = 65\left(\frac{5}{2} - 1.00\right) = 97.5\text{ kN}$$

$$1.4 V_{Rd,c} = 1.4 \times 40 = 56\text{ kN}$$

SHEAR STRENGTHENING IS REQUIRED

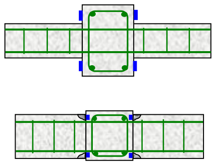
for 97.5 – 56 = 41.5 kN

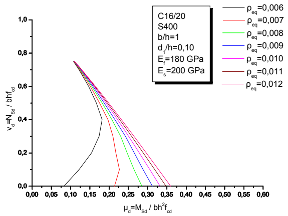
Columns



This is wrong !!

COLUMNS



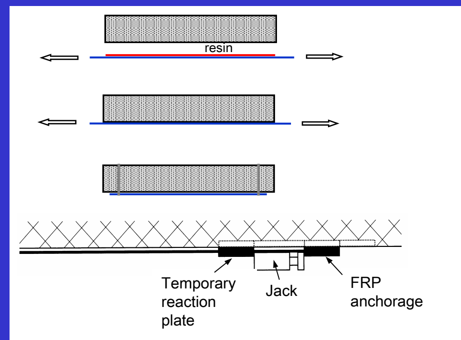


→ Neglect FRP in compression

→ The effectiveness of strengthening increases as the axial load decreases

$$\rho_{eq} = \rho_s + \rho_f \frac{E_f}{E_s} = \frac{A_{s,tot}}{bd} + \frac{A_{f,tot}}{bd}\frac{E_f}{E_s}$$

PRESTRESSED FRP



+ TAKE ADVANTAGE OF PRESTRESSING
+ BETTER USE OF FRP
- MORE BRITTLE RESPONSE
- SPECIAL (AND EXPENSIVE) DEVICES

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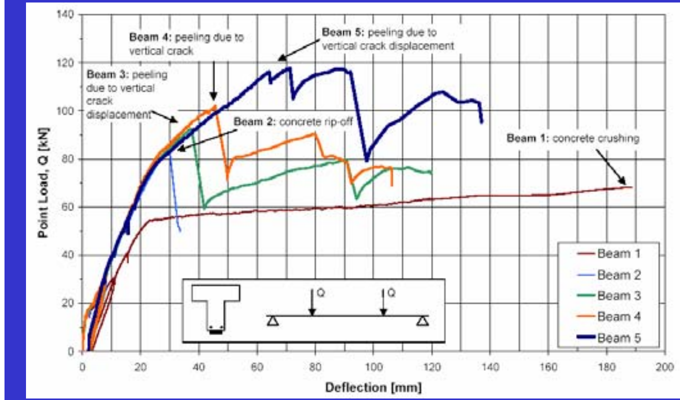
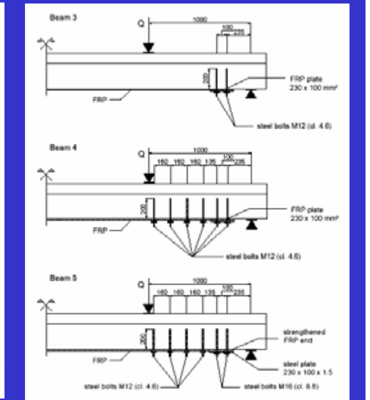
MECHANICALLY FASTENED (MF) FRP





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Shearing

Compression failure

FAILURE MODES

Tension failure

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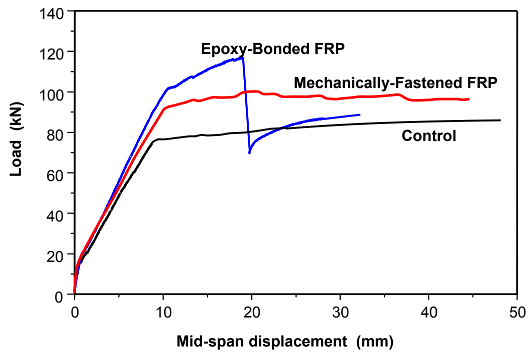

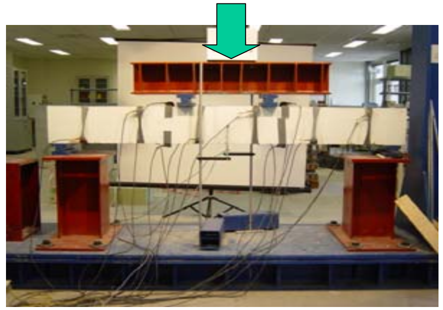

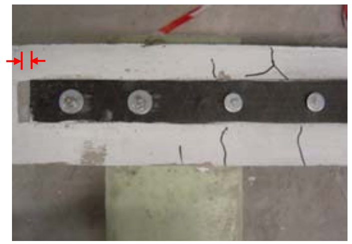

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Near Surface Mounted (NSM) Reinforcement



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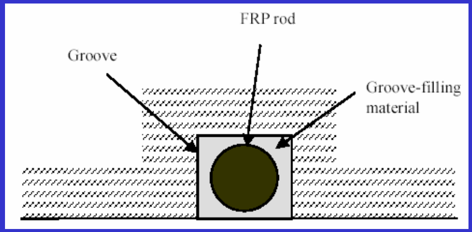
NEAR SURFACE MOUNTED (NSM) FRP



+ IMPROVED BOND BEHAVIOUR
+ BETTER PROTECTION OF FRP
- MORE LABORIOUS & EXPENSIVE SOLUTION
- APPLICABILITY IS LIMITED BY THICKNESS OF CONCRETE COVER

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